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APPLICABILITY AND ECONOMIC EFFICIENCY OF SEISMIC RETROFIT MEASURES ON HISTORIC BUILDINGS OF MID-XXTH CENTURY

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SUMMARY

Reduction of seismic risk through retrofitting of existing buildings serves catastrophy prevention. Planning of interventions on historic buildings differs from that of new ones in an important aspect: the existing construction is basis for all planning and building efforts. Research has been conducted concerning mainly the building stock in Bucharest, Romania, but the correlation with possible results in other locations is taken into account, namely Greece. The work focuses on residential multi-storey mid-rise reinforced concrete frame buildings from the interwar time and deals with two main aspects: the applicability and the economic efficiency of seismic retrofit measures. Several retrofit measures have been analysed, both conservative (steel jacketing, addition of structural wall, braces) and innovative (glass and carbon fibre application). For the calculations several models have been used as follows: simplified regular models based on the height, span, number of bays and frames characteristics of the majority of buildings in Bucharest; building projects following the regulations of the interwar time and finally a real building from the interwar time. The structural performance has been assessed both displacement based and stress-strain based; the results were used to calculate the repair costs after earthquakes of different intensities and the retrofit costs to achieve certain performance levels, in both cases related to building replacement costs. These are summarised in what are called “costs curves”. Further, different aspects of “benefit” of retrofit measures (duration, alteration of historic substance, relocation of inhabitants) are taken into consideration and the hitherto developed model for the choice among these is also presented. It is an integrated decision support system comprising building survey, structural aspects and calculation of costs, and it uses the same building elements as planning basis.

INTRODUCTION

Catastrophe prevention implies the reduction of seismic risk, through the retrofit of existing buildings in order to fulfil requirements of seismic safety. This contribution shows where lay the differences between costs estimation and calculation methods for rehabilitation of historic buildings, when seismic retrofit

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builds a special concern, and develops through the extension of an existing one a method for benefit and costs estimation in case of seismic rehabilitation of inter-bellum buildings in Bucharest, Romania.

Applicability concerns issues like the duration of the measure, together with relocation need of the inhabitants, dry or wet techniques, and the degree, to which aesthetic qualities and the residentiability (usability) of the building are affected by the measure. Within this work not each of this aspects has been addressed. The economic efficiency concerns issues of benefit-costs-analysis. While costs estimation and calculation for retrofit measures build a new thematic, the benefit assessment is even more difficult to make. The difficult part about costs estimation/calculation comes from the fact that until recently research has been carried out for new buildings only, not only concerning the development of new norms but also concerning construction costs.

A database of documented retrofitted buildings for the case study in this work, Romania, is not yet available. In order to correct this, the data have been self generated. There are enough data about retrofit elements, as usual interventions on buildings are made out of different combinations of these actually whole new methods. The idea is to create less complicated models, on which different retrofit elements can be applied. Such are the models „Gregor“ and „Özzi“, but, in order to add realism, also real buildings of the time had to be modelled. Such a building has been simulated as model „Interbelic“ in this project (Bostenaru[1]).

URBAN FRAME

The starting point is a holistic approach to catastrophe management. This takes in consideration natural sciences, social sciences and engineering know-how in an interdisciplinary manner. Capacities and vulnerabilities against natural phenomena are estimated and the measures developed should decrease the vulnerability and increase the capacity. Instead of according the same importance to all parts of a town and handle them in this way, the planning strategy links intervention layers one to another and display intensive zones, for which detailed solutions are to be made, while other zones remain only globally described. Variety of the build substance, research possibilities, urgency of the measures to be taken are only some of the criteria after which the priorities for the deepness of planning for a zone or for a class of buildings are set.

The building and development schemes have changed since the 80s. Numerous actors, who represent different interests, participate in it (Bostenaru[2]). In a schematic representation these can be summarised under the concepts of „publicity“, „experts“ and „affected people“ (Figure 1). Through the implication of this actors at the latest the decision about the adequate retrofit measure will be a multicriteria group decision and replaces herethrough the usual benefit-costs-balancing. The task of the multicriteria decision methodology is ranking of option using several criteria. Different approaches on the technique of multicriteria decision were developed till now in the field of spatial planning (Malczewski[4]). However, most of them are based on the criteria ranking supported through mathematical means with weights. Within this work another way to solve decision technical problem statements has been envisaged. it is a matter of the balancing principle in multicriteria decisions (Strassert[5]). Within this model the criterion scores are held until the last balancing step in the factual level. Not the weighted, normalised sums are compared, but the advantages and disadvantages are confronted. Through this an interactive balancing procedure is created, in which the relative importance of criteria is continuously taken into consideration. This procedure is better suitable for the case of seismic retrofit as the traditional utility-value approach. The „benefit“ of seismic retrofit is not weightable and normalisable, when it concerns human life and other, not financially expressable, for example cultural, values.

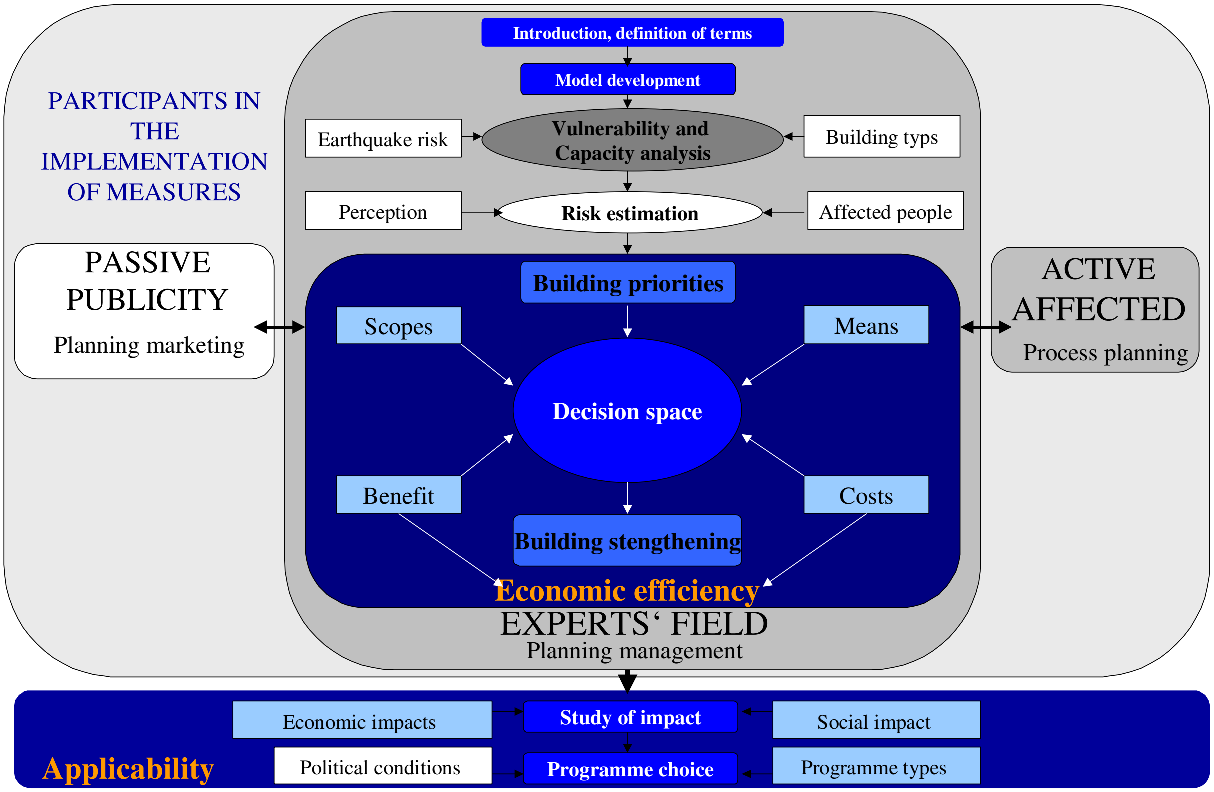


Figure 1: Schema of the coaction of different actors in the decision and implementation of retrofit measures (after Bostenaru[3])

RETROFIT ELEMENTS

There are several attempts to assess the costs for the rehabilitation of a building (Neddermann[6]), but only some of these can be applied in case of seismic retrofit, as aging is a uniformly distributed „illness“ of the building, while retrofit generally affects selected elements. In the meantime there are only few and inhomogeneous databases about the costs of already realised measures for seismic retrofit. The ones accessible at FEMA[7], in the USA, are richer in content, but in Romania only about twenty of what in this work are called „retrofit elements“, are documented from a costs point of view. The idea of the costs calculation for a „retrofit element“ (for example „jacket-column“) was evaluated to be promising, too. For this reason the costs for some of this elements were calculated in the dissertation (Bostenaru[3]). The same elements were estimated then from a structural point of view. These are the so-called „simple models“. A turning point appears when considering that retrofit elements are not applied, as mentioned above, uniformly inside a building. In order to obtain the mean value for a retrofit element, several regular, but whole multi-storey structures, on which the measure had been applied, were considered. These structures were estimated also from a structural point of view within this work. These are the models „Gregor“ (Bourlotos[8]) and „Özzi“ (Öztürk[9]), named after the students, whose works, advised by the author, contain detailed research. This works have shown though, that costs calculation with this method, even if it is well systematised, is time consuming.

BUILDING SURVEY METHOD

Here there will be no detailed presentation of the complex relationships, which lead to the choice of criterion weighting, decision rule and decision support system type. Finally, regarding the general frame of the work, a word has to be said regarding the building survey. In case of retrofitting, the existing building is the basis to go further on. Documentation of the geometric and material characteristics of the building, to use a simplified description, takes place within the building survey. This builds the basis for running simulation, to calculate indicator surfaces for the costs estimation, to design retrofit strategies. The easiest to record is the facade, as it doesn't require to go inside the building, normally associated with disturbance of different kinds. And the facade contains the elements to make simplified vulnerability assessments and also for the indicator surfaces. The importance of the building record for the study of retrofit of buildings cannot be emphasized enough. An aspect of the problematic shown in this contribution is that the development of a costs estimation and even calculation method needs an in-depth analysis of the individual building. However, data of this kind are in most cases needed for decision making on the level of communes. Recent approaches have shown, that the methods, which are used for vulnerability assessment of individual buildings, can be adapted in a simplified way for building classes (Bostenaru[10]). In which way this procedure can be transferred to the retrofit costs assessment, was shown in this work. For priority setting on „communal“, i.e. urban level, two approaches can be followed. Selection of areas requires the area wide implementation in heterogeneous environments, each of them building closed urban units (blocks). Selection of target elements, in this case building categories, is based on the scenario of punctual implementation on individual buildings, which lay irregularly distributed in the whole zone. The connection between these two levels has been set first through procedures of the building survey.

Area wide survey

The parameter for the estimation of risk, hazard, vulnerability and capacity on this level are the hazard estimation, the historical overview of building classes, their own vulnerability and capacity, the built substance, the load bearing structure, the function and the scale. These data can come from the examination of different data sources, from literature studies, from building surveys or construction plans and from enquiries of all kinds. The qualitative building survey is made through careful observation on site. The information is gathered, and a pre-evaluation follows. The focus of the quantitative survey lays in the evaluation. In a first step this means the evaluation of photographs and in a further step the post-evaluation, which serves the correct digital saving (Bourlotos[11]). Through this the geometric characteristics and the topological relationships and their influence on the seismic behaviour are evaluated. An introduction about the social consequences has been made. It doesn't concern the almost catastrophic consequences of the impact of the natural hazard on buildings, but the consequences of the measure for the reduction of the risk itself. The measure should serve to minimise the consequences of the earthquake, but these will be quantified „technically“ as building performance. The building facade builds the basis and orientation for all planning levels and all participating actors. The elements which are needed for decision making can and must be structured during the building survey. And for the retrofit as well as for the costs calculation decisive elements are those of the facade.

Typological survey

Making safe and payable housing available includes environmental and sustainability issues. To build residential buildings which behave well in case of damaging earthquakes is a basic concern for the development of sustainable communities, for which engineers, architects and housing experts play an important role. The Earthquake Engineering Research Institute and the International Association of Earthquake Engineering have a running project to make a web based encyclopaedia about residential building types in earthquake prone areas of the world (Brzev[12]). The scope of the encyclopaedia is to develop a comprehensible global categorisation of housing types, which are presented with use of a standardised format. The Encyclopaedia makes available basic information over the seismic vulnerability and the seismic vulnerability and capacity of different structural systems and materials (Figures 2-8).

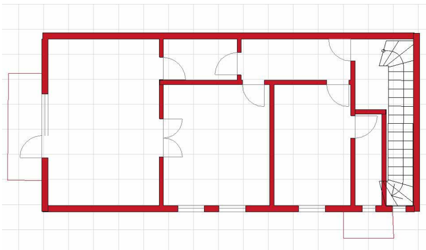


Figure 2: Typical plan - two storey masonry house with wooden floors (from Bostenaru[13])

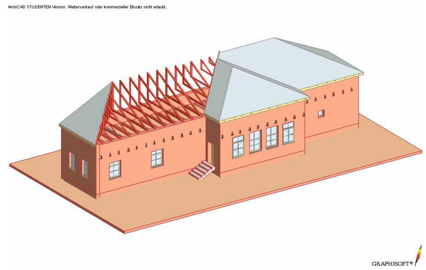


Figure 3: Perspective drawing of key load bearing elements - single storey historical masonry house

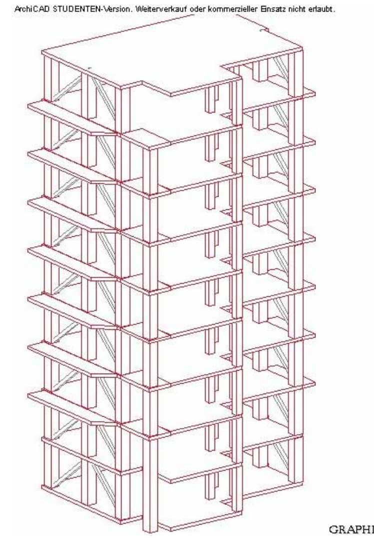


Figure 4: Key structural features - post-war RC frame building with RC diagonals (from Bostenaru[14])

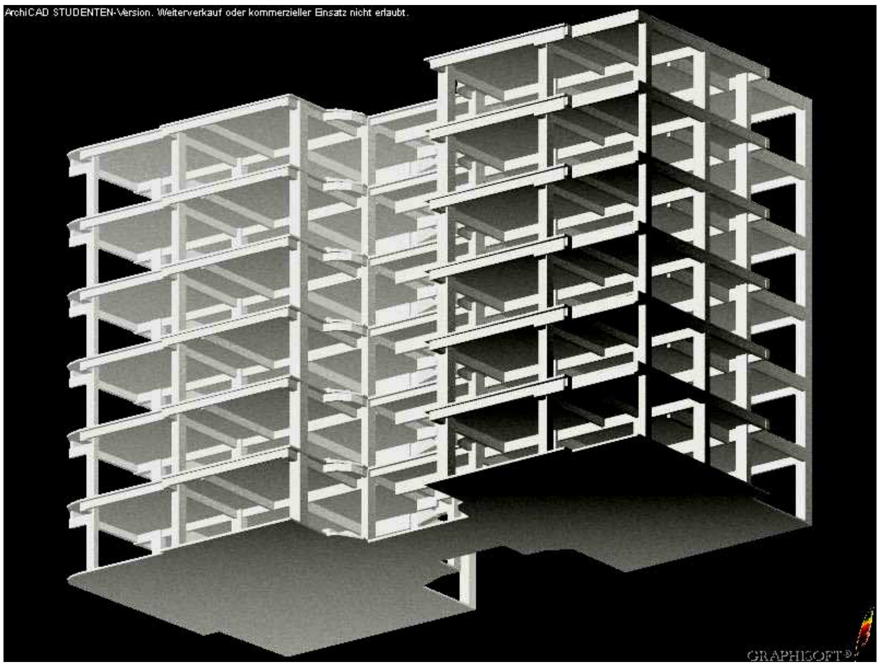


Figure 5: Key seismic features and deficiencies - inter-bellum RC building)

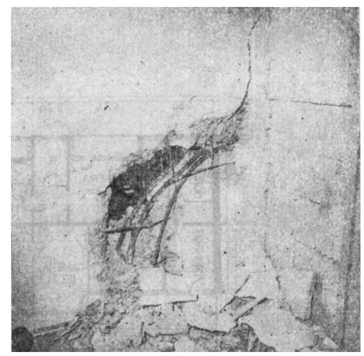


Figure 6: Typical earthquake damage - structural wall building (from Bălan[15])

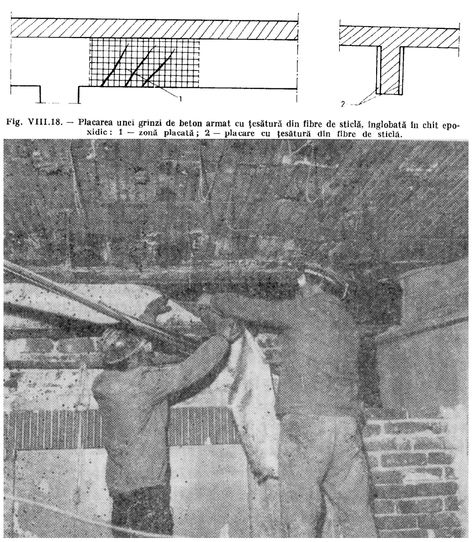


Figure 7: Seismic retrofit technique - inter-bellum building (after Bălan[15])

Figure 8: Photo of a typical building - structural wall building

STRUCTURAL ISSUES

In the years 1918-1940, within two decades of energical construction process, Bucharest has seen the construction of buildings, which have conferred to its centre the looks of today. From an urbanistic point of view Bucharest is the creation of that years. Residential buildings of the pre-war time of WWII, with eight till fourteen floors, were built as reinforced concrete structures with masonry partition walls. These have suffered most (Bălan[15]), as they were built exclusively for resistance to vertical loads and therefore are exposed to high seismic risk. From an urbanistic point of view they are very high for their context, what has been handled through recesses of each floor over the cornice line. Architectonically they are characterised through simplicity, horizontality and different deepness levels. Research over the Bucharest of the inter-bellum time and its buildings is running on high speed, and information about it is both available and reliable (Machedon[16]).

Scope of this work was to assess the structural advantages of different retrofit measures. The same geometrical and material characteristics, which have been regarded previously in the costs calculation, were maintained, and no optimisation has been yet made. It has been always tried to motivate the assumptions, while the outlook of the research work has been described. In order to assess the impact of strong motion on certain building types several approaches have been followed: pushover analysis, dynamic time-history analysis, stress-strain approach, based on the dynamic time-history analysis. In order to see the portability of the conclusions in a wider frame, at least one earthquake outside Romania have been chosen outside Romania. Due to the considerable amount of Greek literature, the Thessalonica earthquake from 1978 has been chosen, as there the same building types as the Romanian inter-bellum buildings are to be found.

First the pushover curves for simple models were computed, an approach often used in literature, in order to compare the performance of retrofit measures. This was it was reproduces, what could have been tested in an experimental laboratory, and applied on progressively complicated models, from regular frame structures up to real building models, with all the irregularities usual in the practice. The results were relativised through the fact that the same was applied in case of the retrofit measures on the same not homogenous building. Finally dynamic analysis has been run under use of three earthquakes of different intensity which affected Bucharest and one which affected Thessalonica, in Greece. Additionally to the already described model buildings two additional structural models have been considered (for detailed description of these models and earthquakes see Bostenaru[1]). This way a section of the strategy part flows also into the project. These buildings are thought as alternatives for existing ones. They have the same qualities like that ones and additionally improved structural qualities. The more complex is the building, the mode influence has the fineness of the finite element mesh on the dynamic time-history analysis simulation.

The innovative part of this study lays in the stress-strain based approach, applied on building models of this size. Such an analysis allows not just the description of failure modes and the determination of limit states, which might be reached by the building, but also the specific determination of the number (Table 1) and, if necessary, the layout (figures 9-11) of the structural members, which suffer a specific damage (table 2). This kind of output can be the input for other interdisciplinary studies. Here the economic view concerning the retrofit/reparation need of damaged elements as opposed to preventive retrofit is of interest (Bostenaru[1]). In this sense also the retrofit of predamaged structures, a problematic perfectly matching into the proposed method, was approached. The adopted methodology has implied the use of several computer tools, beginning with software for conversion of accelerograms, fibre based finite elements (SeismoSoft[17]), spread sheet and database programs (the workflow is shown in figure 12).

Table 1: Cumulated damage percentages for simplified representative models of different heights for the 1977 Vrancea earthquake

Retrofit method	fracture+ crush+ spall+crack	yield+crush+ spall+crack	crush+ spall+ crack	yield+ spall+ crack	spall+ crack	yield+ crack	crack only
4 storey model	0	11.27	0	47.06	0	25.98	16
5 storey model	0	9.79	0	42.55	0	29.36	18.30
6 storey model	0.71	8.10	0	47.14	0	18.81	25
7 storey model	0	14.84	0	40.45	1.86	10.76	32
8 storey model	0	7.26	0	23.99	3.23	5.65	59.68

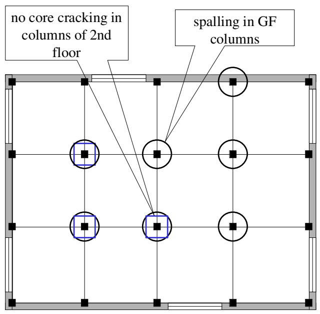


Figure 9: Layout of mostly damaged elements as predicted for model "Gregor", bare structure, discretised in fine mesh, under the effect of the Thessalonica earthquake in 20. June 1978.

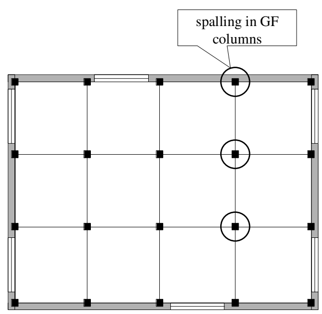


Figure 10: Layout of mostly damaged elements as predicted for model "Gregor", retrofitted with metal jacket, discretised in fine mesh, under the effect of the Thessalonica earthquake in 20. June 1978.

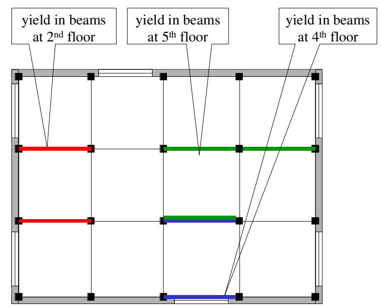
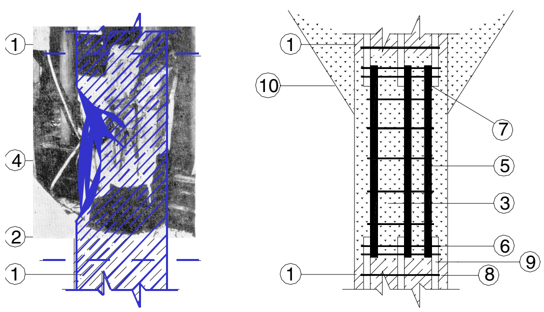


Figure 11: Layout of mostly damaged elements as predicted for model "Gregor", retrofitted with side walls, discretised in fine mesh, under the effect of the Thessalonica earthquake in 20. June 1978.

Table 2: Damage image and reparation provision for a column presenting crush, spall and crack in concrete, eventually yield in steel

COLUMN: CRUSH + spall + (yield) + crack



1. old concrete, 2. damaged old concrete, 3. new concrete, 4. buckled reinforcement, 5. new reinforcement, 6. new stirrups, 7. welded joint, 8. old stirrups, 9. old reinforcement, 10. formwork

<u>Image of damage</u>
Concrete is damaged until the middle of the column, reinforcement is buckled, but not yet fractured.

<u>Reparation measure:</u>
Replace concrete and reinforcement in the damaged zone.

No.	Work	Price (€)
1.	Breaking up masonry near column	52.41
2.	Unloading the column (bolts)	108
3.	Breaking up concrete with chipping hammer	900
4.	Cleaning up the broken concrete	19
5.	Cutting damaged zones of the reinforcement	12
6.	Laying new reinforcement	149.6
7.	Air blasting of concrete and reinforcement	46.08
8.	New stirrups and their fixing	147.4
9.	Anchoring of the stirrups to the reinforcement bars	90
10.	Roughening and air blasting of the concrete surface	72
11.	Setting up formwork	72
	Formwork and support (scantling)	98.75/4
12.	Casting concrete	136
13.	Removing formwork	72
14.	Plastering (outside and inside)	225
	PRICE	2126.18 (~2000)

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Otpt No:  73   Time= 9,3360,  spallig reached.    Elm:   Cb51ba.  Unc Conc Strain =   -0.002173 - G.p.(b)
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Otpt No:	Time=	reached	Elm:	Mat 1	Mat 2	Strain =	Gauss point
1	0.1500,	crack_cover	bmz3412.	Unc	Conc	0.000107	G.p.(b)

ID	Otpt No:	Time=	reached	Elm:	Mat 1	Mat 2	Strain =	Gauss point
1	1	0.1500,	crack_cover	bmz3412.	Unc	Conc	0.000107	G.p.(b)

Gesamtsumme von ID	yield	crush	spall	crack_core	crack_cover	element
15	4	1	2	4	4	bmx121
14	4		2	4	4	bmx122
8				4	4	bmx161

Figure 12: Workflow in data processing

ECONOMIC CALCULATIONS

The innovative contribution is to make the transition from a purely structural view to one, which is combined with economical aspects. The main focus lays in the modelling of interdependency relationships, so that the behaviour of the same group of elements in different states can be compared on a same nominator. The roots for this idea lay in already carried out studies for other technical aspects of architecture. While buildings constitute complex structures out of different elements, for this study rough structures, consisting out of a well defined and limited number of elements have been chosen. This way building elements can be used as device directory for costs calculation in tendering-allocation-billing modules. The costs for these elements shall not be computed anymore as mean value of those in existing buildings, but can be really lead back to the steps in the device, which caused them. The decision algorithm described in this study helps the choice of retrofit elements. Further division levels are here the interior/exterior wall in load-bearing parts as well as a division of this in linear, surface and node elements (Bostenaru[18]).

A retrofit element (Table 2) consists of all the works which have to be made in order to assure the strengthening, reparation, rebuild and even new build of a structural member. In case of building retrofit it cannot be talked of new building elements only, but also not of old ones only. Therefore the considered elements are called „retrofit elements“, and there are four type of them: old elements, which are simply strengthened building elements; new elements, which are totally new elements, added to the existing building substance, in which case a special attention has to be paid to the architectural connection between old and new; retrofitted elements, which are existing elements with new extensions, where the new material has to be well connected to the old one; and finally replaced elements, which are newly build elements instead of the deteriorated old ones.

The efficiency evaluation is based on the concept of performance levels (SEAOC[19]). The study does not aim a continuous curve of costs depending on the measures. It aims much more to present levels. The costs of the measures, which are necessary, in order to assure, that a building reaches a certain performance level, change depending on the application moment of the retrofit measure. In order to determine the economic efficiency both the costs of construction measures before (table 3) and after an earthquake have to be considered (table 4, figure 13). Several scenarios, based on the measure levels above, have been researched. Such an example is shown in figure 14. Basically four kinds of retrofit have been considered: the new building is designed earthquake safe, the undamaged building is retrofitted, the predamaged building is repaired and retrofitted and finally the collapsed building is demolished and replaced through a new, earthquake safe building.

Table 3: Costs estimation for retrofit methods (after Bostenaru[3])

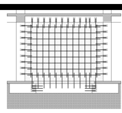
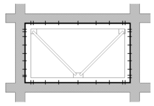
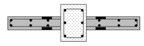
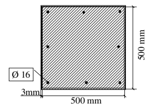
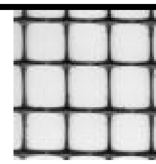
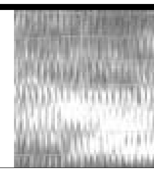
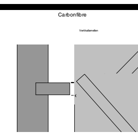
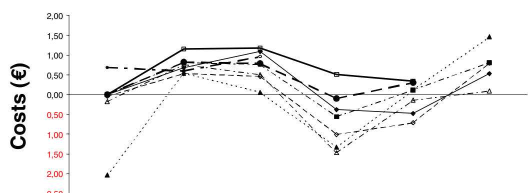
Retrofit							
	Structural walls	Steel diagonal	Side walls	Steel jacketing	Polymer re-inforcement	Glass fibre matt	CFK lamellas
Price	103622 €	87624 €	102960 €	55152 €	29296 €	71488 €	56099 €

Table 4: Savings in reparation cost in €

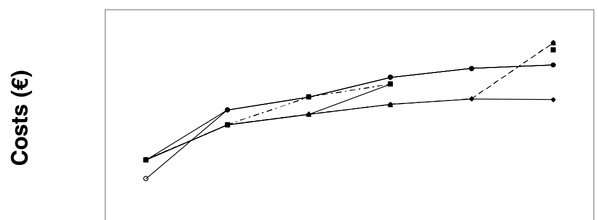
Earthquake \ Model		Gregor				Özzi					
		metal	sidewalls	braces	structural wall	braces 1	braces 2	braces 3	braces 4	braces 5	Interbelic
Vrancea	1977	38618	46800	71632	12832	0.02	46100	74000	-51850	-84000	128400
	1986	-108920	-133616	-168351	55648	-3350	36300	31400	-137250	-126100	193338
	1990 (1)	2478	24081	-47306	-20306	-152550	36450	4050	-180900	20250	352400
	1990 (2)	9089	34758	-22710	-30460	-13300	51600	33950	-199600	-25450	22000
Thessalonica		-6800	41500	-4950		0	55100	51900	-76150	20600	195463
1977+1977			83000			0.04	78400	79800	69550	59400	
Th.+Th.			44600			0.03	55750	53650	-14150	53650	
1986+1977			56850			51250	40550	65300			



	Özzi braces 1	Özzi braces 2	Özzi braces 3	Özzi braces 4	Özzi braces 5	Interbelic
1977	0,00	0,68	1,09	0,38	0,48	0,53
1986	0,04	0,53	0,46	1,01	0,71	0,80
1990,1	2,04	0,54	0,06	1,33	0,11	1,46
1990,2	0,18	0,76	0,50	1,47	0,14	0,09
Salonic	0,00	0,81	0,76	0,56	0,12	0,81
1977+1977	0,00	1,15	1,17	0,51	0,34	
sal+sal	0,00	0,82	0,79	0,10	0,30	
1986+1977	0,69	0,60	0,96			

Model and retrofit method

Figure 13: Rapport between the post-earthquake repair costs and the pre-earthquake retrofit costs exemplified for models "Özzi" (ideal) and "Interbelic" (real building)



	1990,1	1990,2	1986	1977	1986+1977	1977+1977
none	276750	422350	465950	506950	529700	526850
	276750	422350	465950	506950	529700	763015.16
B1	276750	422350	465950	506950		763015,16
	276750	422350	465950	591073.2		763015.16
B4	276750	422350	537385,26	591073,2		732373,2
	276750	483835.26	537385.26	619185.26	655735.26	670185.26
B5	198985,26	483835,26	537385,26	619185,26	655735,26	670185,26

Bemessungsbeben

Figure 14: Optimisation example for retrofit with braces on model "Özzi": more retrofit elements at exceedance probability of a stronger earthquake

In figure 14 the progressive retrofit with braces of model Özzi had been considered. Sketches of all these methods are later shown in table 5. B1 represents the lightest retrofit, B5 the strongest. The retrofit measures have been applied "later" on the "Bemessungsbeben" scale, thus for example the first and second line shows the costs for the possible earthquakes considered if for impact of single earthquakes retrofit in the variant "braces 1" is used, then braces are added to reach the layout of "braces 4" and the first cumulated earthquake damage is seen on these, the further braces are added to reach the layout of "braces 5" and the cumulated earthquake damage of stronger earthquakes is seen on these. For the third line the layout "braces 4" is introduced before the very strong earthquake in 1977. For the fourth line the layout "braces 4" is introduced before the strong earthquake in 1986. Compared to this for the fifth line what changes is the introduction of supplementary braces before cumulated earthquake effects are achieved. Finally, for the last line, this strongest retrofit is introduced before the place where the strong earthquake from 1977 is on the axis. To be noted is that here, like in figure 13, a family of curves results.

In figure 15 a synthetic view of the costs curve concept is provided. On the right side (bottom) a graph pointing to the costs levels outlines the hypothesis from which the concept went out. This graph shows the additivity of the daylight quotient in a building. Additional windows placed in cascade to the original façade line are helping that the minimum necessary is reached. By inverting this graph the hypothesis curve for the costs was generated. It should show that providing additional strength, stiffness and/or ductility helps reaching a minimum on retrofit costs. For earthquakes of each probability of exceedance such a curve can be traced. On the left side the same type of graph as in this hypothesis is derived from an existing approach in earthquake engineering. The starting superposition of curves is an idealisation after Paulay[20], depending on the "design earthquake" ("Bemessungsbeben" in original German). The "Bemessungsbeben" is the correspondent concept in German speaking countries for the "performance levels". The curves have been mirrored to get the succession from low to high on the X axis (from the earthquake at which immediate occupancy is targeted to that taking into account to design the structural safety), and then the curves scaled to a more realistic rapport. Finally the hypothesis is proven and shown on the example of the retrofit measures with side walls for model "Gregor" (top right).

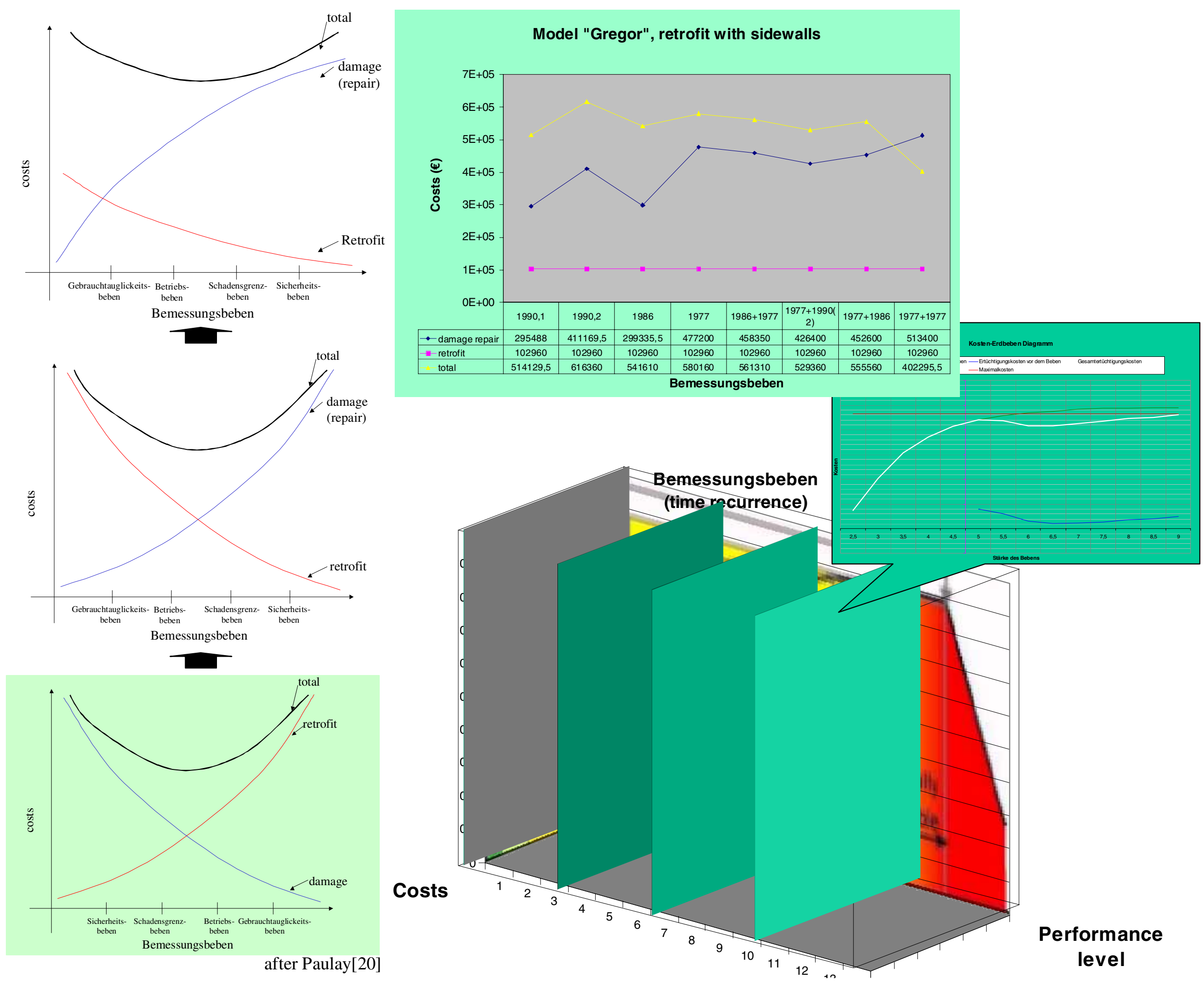


Figure 15: The concept of costs curves (after Bostenaru[3])

Figure 16 shows a numerical correlation example between the model of the costs curves and the idealised curve obtained through theoretical considerations. To be noted is that these curves are not scaled to serve reaching a certain performance level and also assumptions in the structural modelling may lead to inexactitities, but still, it provides an exemplification of the algorithm in a model limitedly calibrated.

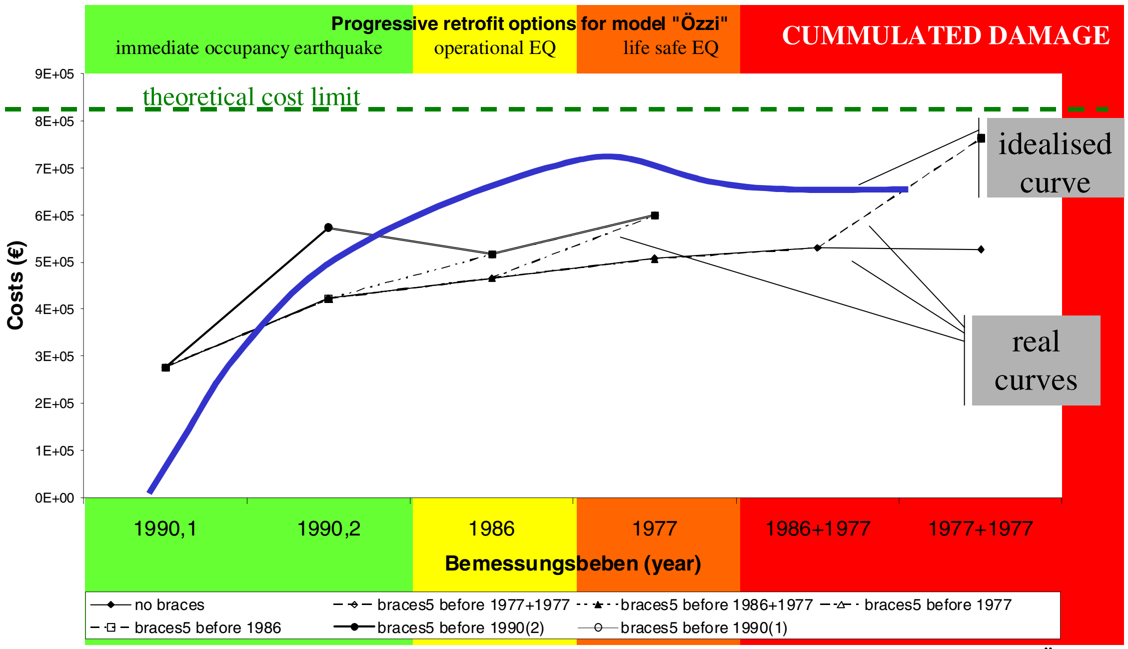


Figure 16: Example of costs curves for different moments in time when retrofit measures are applied on model "Özzi"

DECISION SYSTEM

Estimation of risk has deep sociological roots. It concerns first the affected people: for an analysis the number of potentially affected, the number of the user of a building conform standard densities of the corresponding use class and the number of users of the building after old surveys as well as after new surveys are needed. Further also the importance class of the building, as stated in the Romanian building code P100-92 (MLPAT[21]), is implied. The perception of risk takes place on a sensible background after the construction measures taken in the Ceausescu-Aera in a situation determined today especially from the current law giving.

The method to be used is called, according to the procedure, „balancing", and has been developed by Prof. Strassert [5] at the University of Karlsruhe. It is a kind of pair wise comparison method, which has its roots in the research work of Saaty (Malczewski[4]). The method developed by him differs from traditional utility-value approach. The core of the method lays in the fact, that no numbers are assigned to the weighted criteria, these are kept „as they are". Then a balancing takes place, while answering questions like „is this advantage worth it, to put up with the other two disadvantages, which appear simultaneously?". This way advantages, which come from totally different fields, which have very different, and sometimes no numerical measure units, can be weighted. This principle can be well used for retrofit, where otherwise structural performance and aesthetical changes are difficult to compare, be well used. Thus the criteria do not result in a score, which shall be added mathematically to a fulfilment extend average, but are considered as pairs until a decision is made. Tables 5 and 6 show exemplary data tables for retrofit layout alternatives and for retrofit type alternatives. For each actor a criterion was chosen respectively: K1 for the investor (the retrofit costs), K2 for the structural engineer (the so called equivalent elements, computed as rapport between the reparation costs to the average repair costs of one of the most damaged elements), K3 for the architect (the influence on the appearance of the building) and finally K4 for the user (the amount on disturbance of the activities inside the building).

Table 5: Balancing criteria for retrofit layout options (after Bostenaru[3])

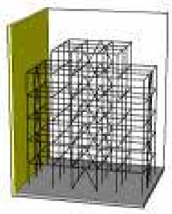
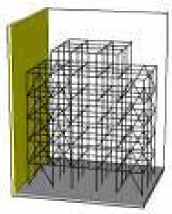
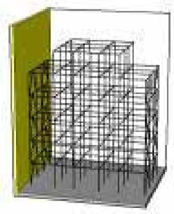
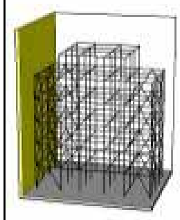
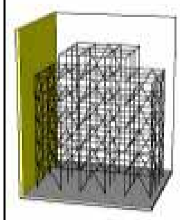
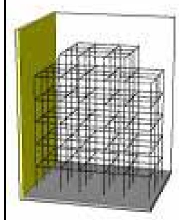
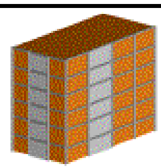
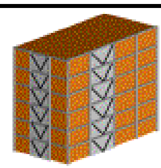
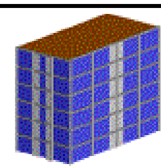
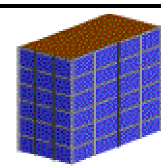
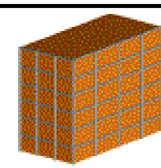
Options/ Layout \ Criteria	 S1	 S2	 S3	 S4	 S5	 Null-Option
K1 Costs (€)	74785	67987	67987	135973	176765	0
K2 Eqv. Elements (Number)	$\frac{595400}{2000}$	$\frac{605250}{2000}$	$\frac{606650}{2000}$	$\frac{596400}{2000}$	$\frac{586250}{2000}$	$\frac{526850}{2000}$
K3 Arch. (Ranking)	E	B	D	C	F	A
K4 PM	V	VI	II	IV	III	I

Table 6: Balancing criteria for retrofit type options (after Bostenaru[3])

Options \ Criteria	 S1	 S2	 S3	 S4	 Null-Option
K1 Costs (€)	103622	87624	102960	55152	0
K2 Eqv.El. (Number)	$\frac{345950}{2000}$	$\frac{353700}{2000}$	$\frac{411170}{2000}$	$\frac{273885}{2000}$	$\frac{376411}{2000}$
K3 Arch. (Ranking)	E	C	D	B	A
K4 PM	V	II	IV	III	I

A further step in testing the general validity was the use of the same methodology for simplified models of real buildings with the same typology (Figures 14-16) as those which have been studies extensively. This examination has shown, that the methodology proposed is valid for them. The integration in the general frame of structural performance assessment has been made through comparison of computed damage types with real damage types. For this purpose a matrix of the damages suffered by inter-bellum buildings has been used (Bostenaru[22]). It was proved again, that predictions for buildings with the same geometric characteristics as those, which had build the object of this study, lay close to reality (Bostenaru[3]). These case studies allow trying out the method on concrete examples.

Figure 17: Façade and side wall view in a RC frame building with masonry infill in avant-garde style in Thessalonica, Greece.

Figure 18: Façade detail of a block of flats in Bucharest, Romania

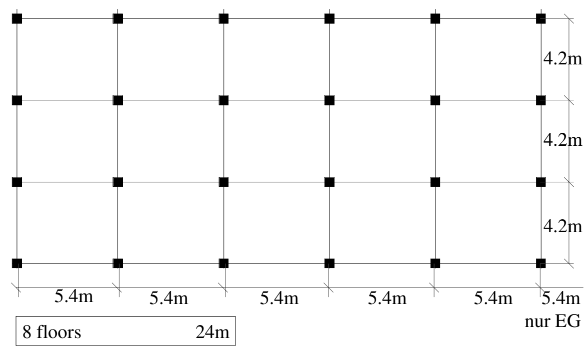


Figure 19: Plan scheme of a building designed taking the Naum Ghica building of Marcel Iancu as a model

RESULTS

Research focused on building models in field of a framework for an integrated information and decision tool. The use of computers generates in each realm of day-to-day life an automatic increase of information density. In order to avoid this, a structuring model of existing buildings was developed. The focus lays in the identification of suitable spatial elements of a building as a basis, in order to connect the factual (sachlich) data. The choice of such elements takes into consideration different information requirements of the actors, which participate in decision making for the process of seismic retrofit of a building. They come from different fields, like architecture, engineering and economic sciences and exchange information using digital building models. Identification of the interface between the project for structure and that for realisation is the main task to be fulfilled through this type of systematisation of data. New is also the research concerning visual recognition characteristics of structural elements of a building.

Another results have been reached concerning costs calculation methods. The developed methodology makes use of the newly defined „retrofit elements“, in order to assess retrofit costs of a building in a zone, where no statistical data are available, like those, which are used in common estimation methods. One of the advantages of this method is breaking up with statistics, allowing for a customised approach in the application of the method on different building types. The performance based approach can be extended through a third dimension for the economic efficiency.

Some contacts have been built up with researchers from Greece and Italy, in order to learn about approaches to the retrofit of monuments. The end scope is to define such retrofit elements for architecturally important constructions, which don't change their character. It is possible to develop guidelines for the characters to be maintained in case of a building, which belongs to a certain architectural style, and to make available a catalogue with the corresponding construction elements for that case. This doesn't replace consulting an architect, though. For example retrofit measures, which are based on the extension of the active element section, generate biggest problems for buildings with architectural or environmental value. The steps of this method reach a corresponding depth, in order to be able to design appropriate measures for this kind of historic buildings.

OUTLOOK

Searching for a faster costs estimation method the thoughts were oriented to the way how this is made for new buildings. The costs estimation for new buildings is made using the surface indicator. For buildings of certain use the surfaces „foreseen" for certain functions are calculated. Then, with regard to a costs database, five buildings with similar characteristics (concerning their structure, their function, their size, their foundation conditions, site and building year) have been chosen. For this the same surfaces, which are calculated for a new building, are documented in the database. A mean value is computed and, as a result, the costs for a new building are estimated. The same approach is targeted for seismic retrofit. In this case the indicator are not the function surfaces, but the wall, especially the facade surfaces. The essential in the adaptation would be, that while computation is based in case of a new building on the computation of costs surfaces in ground floor, it has to be aimed in case of retrofit on costs surfaces of the facade, as according to insights of the one researched in this work, measures on the facade spare most the building substance and the use inside the building. Further research in this direction will comprise: modularisation, promotion of communication and co-operation between participants in planning process (experts/publicity/affected people) and the integration of computer supported tools in a database structure.

The simplified models „Gregor" and „Özzi" will be refined progressively, in order to see the amount of similarity in results with the real building model „Interbelic". Depending on this results different refinements will be made, in order to bring the building closer to other real ones, as well as an optimisation of retrofit measures, in order to see a wider image of adequate strengthening and potential requested reparation techniques. Further studies will envisage another building groups for typical construction types as well, so that conclusions about the variation over building classes can be drawn out. These are going further as the parallel study, which has been shown here, as they include exact costs calculation. Structural studies when designing retrofit measures take long, and there are no tools for costs calculation, which causes thus unnecessary loose of time. Through this method the building survey and the collection of data for costs determination take place at the same time, when engineering measures are in the project phase, so that costs estimation can take place immediately after the retrofit project.

As the method has not been applied yet, no affirmations can be made about the reliability of computed costs. Earthquake safe systems can only be estimated, when other methods or databases have found a use in the same region, and this is not the case for Romania. An advantage of the method is though, that out of the same database a device directory can be generated. The modular structure of the database allows it to begin with the generalisation of the methodology. As soon as the method has been used for own projects, the values can be saved in a standardised format, in order to build a database of retrofitted objects. This will be of use for the costs estimation of future similar projects.

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